Methods for Maintaining Traffic Sign Retroreflectivity

PUBLICATION NO. FHWA-HRT-08-026 NOVEMBER 2007

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

Signs are considered essential to communicating regulatory, warning, and guidance information. It is critical that signs are able to fulfill this role during both daytime and nighttime periods. The ability of a sign to fulfill its role during nighttime periods is provided by a unique form of reflection known as "retroreflectivity." The retroreflectivity of signs, however, degrades as the signs age in the field. A new standard in the *Manual on Uniform Traffic Control Devices* (MUTCD) requires that agencies maintain traffic signs to a minimum level of retroreflectivity. Various methods can be used within an agency's sign management processes to meet and maintain a minimum retroreflectivity requirement for traffic signs. This report describes methods for maintaining traffic sign retroreflectivity that can be used by agencies to:

- Systematically identify those signs that do not meet the minimum level of retroreflectivity.
- Initiate activities that will upgrade signs that fall below the minimum required levels.
- Monitor the retroreflectivity of in-place signs.
- Create procedures that will assess the need to change practices and policies to enhance the nighttime visibility of signs.

It is not appropriate to prescribe a single detailed method for all agencies to follow. The most cost effective and efficient method to maintain sign retroreflectivity will vary by agency, depending on the types of signs in service and the traffic and environmental conditions. Therefore, this report outlines several possible methods an agency can employ to maintain a minimum level of traffic sign retroreflectivity.

Michael F. Trentacoste
Director, Office of Safety
Research and Development

Form DOT F 1700.7 (8-72)

1. Report No. FHWA-HRT-08-026	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Methods for Maintaining Traffic Sign Retroreflectivity		5. Report Date November 2007
		6. Performing Organization Code
7. Author(s) Paul J. Carlson and Matt S. Lupes		8. Performing Organization Report No.
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, TX 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Project No. 474840
12. Sponsoring Agency Name and Address Office of Safety Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report, March 2003–June 2005
		14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with the U.S. Department of Transportation and the Federal Highway Administration.
Project Contracting Officer's Technical Representative: Kenneth S. Opiela
Turner-Fairbank Highway Research Center Safety Research and Development (HRDS-5)
Federal Highway Administration (HSA-10)

16. Abstract
In response to a Congressional directive, the FHWA has established minimum maintained traffic sign retroreflectivity levels that are incorporated into the *Manual on Uniform Traffic Control Devices* (MUTCD). One of the concerns expressed by agency personnel responsible for being in conformance with required minimums is the potential increase in tort exposure. The FHWA has developed retroreflectivity maintenance methods that, when implemented as intended, provide agencies with a flexible means of being in conformance with required minimum retroreflectivity levels and provide protection from potential tort claims. Other properly supported methods (i.e., through the completion of an engineering study) may be used to maintain signs at the required minimum retroreflectivity levels. Agencies can use the information in this report to help determine which retroreflectivity maintenance method or combination of methods best suits their needs.

17. Key Words **RETROREFLECTIVITY, TRAFFIC CONTROL DEVICES, TRAFFIC SIGNS, RETROREFLECTIVE SHEETING MATERIAL, SIGN MAINTENANCE, MINIMUM RETROREFLECTIVITY, RETROREFLECTOMETER**	18. Distribution Statement No restrictions. This document is available to the public through: National Technical Information Service 5285 Port Royal Road Springfield, VA 22161		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 47	22. Price

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

BACKGROUND

One of the Federal Highway Administration's (FHWA) primary goals is to improve safety on the nation's streets and highways.[1] Approximately 42,000 people have been killed on U.S. roads each year for the last eight years.[2] While only a quarter of travel occurs at night,[3] about one-half of the traffic fatalities occur during nighttime hours.[2] This translates to a nighttime fatality rate that is approximately three times greater than that of daytime. There are many reasons for this disparity, and no one factor can be singled out. It is, however, reasonable to expect that critical traffic signs be visible to drivers at night to facilitate night driving.

Maintaining traffic sign retroreflectivity is consistent with the FHWA's goal of improving safety on the nation's streets and highways. Safety and operational strategies are dependent on sign visibility that meets the needs of drivers. The FHWA expects that improvements to nighttime visibility of traffic signs will help drivers better navigate the roads at night and thus promote safety and mobility. Improvements in sign visibility will also support the FHWA's efforts to be responsive to the needs of older drivers whose visual capabilities are declining. This is important because the number of older drivers is expected to increase significantly in the coming years. Currently, 26.2 million drivers are 65 or older, and by 2010 an estimated 33.7 million drivers will be 65 or older.[4]

The opening statements of the *Manual on Uniform Traffic Control Devices* (MUTCD) in Section 1A.01 define the purpose of traffic control devices and the principles for their use to be the promotion of highway safety and efficiency by providing for the orderly movement of all road users.[5,6,7] Those devices notify road users of regulations, provide warning, and give guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream. (Note: The MUTCD is incorporated by reference in 23 CFR 655.601. It is available as prescribed in 49 CFR Part 7 and on the FHWA's Web site at http://mutcd.fhwa.dot.gov.) Requirements for nighttime sign visibility have been included in every version of the MUTCD since the first edition in 1935. The latest edition of the MUTCD, the 2003 edition, continues to address the visibility of signs. Three pertinent sections include: Section 2A.09 Maintaining Minimum Retroreflectivity, Section 2A.08 Retroreflectivity and Illumination, which states, "[r]egulatory, warning, and guide signs shall be retroreflective or illuminated to show the same shape and similar color by both day and night, unless specifically stated otherwise in the text discussion in this Manual of a particular sign or group of signs," and Section 2A.22 Maintenance, which addresses maintenance of traffic signs.

These MUTCD provisions have tasked each agency with actively managing its traffic signs according to the MUTCD guidance and ensuring that its traffic signs are performing as they are intended. It is generally believed that maintaining the daytime performance of traffic signs (i.e., placement, clarity of message, adequate sight lines, redundancy, and color) is more easily accomplished than maintaining the nighttime performance. Nighttime performance of traffic signs can be more difficult to maintain for a variety of reasons. One of the primary differences between daytime and nighttime sign performance is a material property called retroreflection. Retroreflection is a special type of reflection that redirects incident light (i.e., from headlights) back toward the source. In the case of highway application, traffic signs are made with retroreflective sign sheeting material that redirects headlamp illumination back toward the vehicle, thereby making the sign visible at nighttime to the vehicle driver. The specific measurement of retroreflection that is of interest is the "coefficient of retroreflectance," abbreviated as R_A. The FHWA has adopted the SI units for retroreflection; thus R_A is measured in units of candelas per lux per square meter ($cd/lx/m^2$). When discussed in quantitative terms, the coefficient of retroreflection is commonly referred to as retroreflectivity. Throughout this document, the term retroreflectivity will be understood to mean the coefficient of retroreflectivity (R_A), unless otherwise stated.

The nighttime visibility of traffic signs that is provided through retroreflective sign sheeting materials is difficult to assess during daytime conditions using visual inspection methods. Furthermore, the retroreflective properties of all sign sheeting materials degrade over time making signs progressively less visible (i.e., less bright) at night. Environmental conditions, such as UV-radiation from the sun, moisture, and pollutants cause a substantial amount of the deterioration in retroreflective performance. However, loss of retroreflectivity can also occur due to vandalism, such as paint ball shots, gunshots, and spray paint. A good overall set of guidelines for the general maintenance of traffic signs is provided by the FHWA at http://www.fhwa.dot.gov/tfhrc/safety/pubs/90002/intro.htm.

As signs degrade and become less retroreflective, their effectiveness in communicating regulatory, warning, and guidance messages to road users at nighttime diminishes to the point that they cannot be seen or read in time for the driver to react properly. Thus, to maintain nighttime effectiveness, signs must be replaced before they reach the end of their useful retroreflective life. Until recently, little information was available about the levels of retroreflectivity necessary to meet the needs of drivers and thereby define the useful life of signs.[8] Research has led to the development of recommended minimum maintained levels of traffic sign retroreflectivity for regulatory, warning, and guide signs for currently available materials, vehicle fleet characteristics, and capabilities of the driving population.

The FHWA developed minimum maintained traffic sign retroreflectivity levels in response to a Congressional directive in the Department of Transportation and Related Agencies Appropriations Act, 1993 (Public Law 102-388; October 6, 1992). Section 406 of this Act directed the Secretary of Transportation to revise the MUTCD to include a standard for minimum levels of retroreflectivity that must be maintained for traffic signs and pavement markings, which apply to all roads open to public travel. As part of the FHWA's plan to meet the Congressional directive described above, the FHWA has outlined methods that agencies can implement to maintain minimum traffic sign retroreflectivity levels in conformance with the MUTCD requirements. Furthermore, changes to Section 2A.22 of the MUTCD will clarify traffic sign maintenance criteria. As a result of rulemaking, agencies will need to implement sign maintenance methods that incorporate the consideration of minimum retroreflectivity levels to provide for nighttime visibility of signs. This document provides general information on methods for maintaining minimum traffic sign retroreflectivity levels.

RETROREFLECTIVE SHEETING MATERIALS AND STANDARDS

Agencies updating their policies regarding retroreflective sheeting materials for traffic signs find that although there are more materials available today than ever before, there is very little guidance on the effective use of these materials for specific applications or on the adequacy of the materials for conditions within an agency's jurisdiction.

Many agencies look to the American Society for Testing and Materials (ASTM) specification D4956, *Standard Specification for Retroreflective Sheeting for Traffic Control*, for information concerning the most applicable use of certain kinds of materials.(9) D4956, however, only provides very general descriptions of the materials, which are grouped into "Types" based on a limited set of attributes. Table 1 provides the descriptions of the types of materials listed in the current version of ASTM Specification D4956-05.

Table 1. ASTM Retroreflective Sheeting Type Descriptions.

ASTM Type	ASTM Description	Typical Construction	Suggested Use	Typical Applications
I	Medium intensity	enclosed lens	none provided	permanent highway signing, construction zone devices, and delineators
II	Medium high-intensity	enclosed lens	none provided	permanent highway signing, construction zone devices, and delineators
III	High-intensity	encapsulated glass beads	none provided	permanent highway signing, construction zone devices, and delineators
IV	High-intensity	microprismatic	none provided	permanent highway signing, construction zone devices, and delineators
V	High-intensity	metallized microprismatic	none provided	delineators
VI	Elastomeric high-intensity	vinyl microprismatic	none provided	orange temporary roll-up warning signs, traffic cone collars, and post bands
VII	Super-high-intensity	microprismatic	medium and long road distances	permanent highway signing, construction zone devices, and delineators
VIII	Super-high-intensity	microprismatic	medium and long road distances	permanent highway signing, construction zone devices, and delineators
IX	Very-high-intensity	microprismatic	short road distances	permanent highway signing, construction zone devices, and delineators
X	Super-high-intensity	microprismatic	medium road distances	permanent highway signing, construction zone devices, and delineators

The FHWA Retroreflective Sheeting Identification Guide–September 2005, which lists the materials sold under each type designation as of the date of the guide, can be accessed at http://safety.fhwa.dot.gov/roadway_dept/docs/retrore_sheet_id.pdf.

REPORT ORGANIZATION

The FHWA has outlined maintenance methods that are intended to provide agencies with a flexible means of conformance with the MUTCD requirements for minimum retroreflectivity of traffic signs and provide protection from potential tort claims. The purpose of this report is to describe the methods shown in table 2 that can be used to maintain minimum retroreflectivity levels.

Table 2. Outline of Methods for Maintaining Minimum Retroreflectivity of Traffic Signs.

Chapter	Method	Description	Advantages	Disadvantages
2	Combination of Methods or Other Method	Agency blends different methods or adopts customized method (based on engineering study).	Customized method by agency to achieve effectiveness and efficiency.	Potentially labor and time intensive depending on level of engineering study.
3	Nighttime Visual Inspection	Assessment conducted according to procedure by trained inspector.	Less time consuming and the overall appearance of signs are evaluated.	Subjective and overtime pay for late-evening labor.
3	Measured Sign Retroreflectivity	Signs are measured with an instrument according to procedure.	Direct measurement without subjectivity and objectively evaluate questionable signs	Time consuming and unable to evaluate other factors affecting sign's appearance.
4	Expected Sign Life	Signs replaced based on age, warranty, or degradation of sign sheeting.	Develop local expected service life and easily implemented.	Sign sheeting type and expected life needs to be known and tracking installation date of sign.
4	Blanket Replacement	Replacement of all signs at specified intervals based on shortest life of material used.	Effectively replaces all signs at once.	Potential waste of relatively new signs.
4	Control Signs	Replacement of signs based on a sample set of control signs.	Less labor intensive and develops local sign life expectancy.	Control sign sample set must be representative and monitored.

CHAPTER 2. RETROREFLECTIVITY MAINTENANCE METHODS

Traditionally, it has been up to Federal, State, and local agencies to manage and maintain their traffic signs in accordance with the MUTCD standards. As a result, agencies have implemented different methods to manage traffic signs that reflect local conditions, needs, and priorities. The management process begins with agency policies and practices regarding the use of retroreflective materials in the fabrication of new signs. Agency policies have often been driven by the costs of the various retroreflective materials. Once new signs have been deployed, there has been less attention paid to the adequacy of the retroreflectivity provided by an individual sign. By and large, the most common method used to trigger maintenance of traffic sign retroreflectivity has been visual inspection. However, other methods have been tested and implemented including measurement of retroreflectivity and scheduled replacements based upon sign age.

The establishment of minimum maintained traffic sign retroreflectivity levels in the MUTCD requires that agencies adopt one or more acceptable methods. This provision was intended to assure that agencies use methods that will be effective in maintaining nighttime visibility for their deployed traffic signs. This minimum standard has raised concerns among State and local agencies.

One of the main concerns is associated with the potential increase in tort exposure once numerical values are tied to minimum retroreflectivity levels for traffic signs. In 1998, a national survey was conducted asking if agencies expected "an increase in tort claim lawsuits as a result of the minimum retroreflectivity values."(10) Two-thirds of the respondents replied that their agencies did expect an increase in tort claim lawsuits if minimum retroreflectivity levels for traffic signs were implemented. The survey respondents claimed that "whether the retroreflectivity contributed to the accident or not, the lawyers will be aware of the minimum values and will use them against the State."

In order to minimize the risk to an agency of being found negligent in meeting the requirements for minimum traffic sign retroreflectivity, a sign maintenance program must be provided in order to ensure the nighttime visibility of signs. This approach has been effective in related tort claims against agencies. Conducting and maintaining an inventory of devices, replacing devices at the end of their effective lives, knowing the laws relating to traffic control devices, and applying State traffic control device specifications and standards are four basic principles suggested by the *ITE Traffic Sign Handbook* to "significantly reduce tort liability lawsuits involving traffic control devices."(11) It follows that sign maintenance methods need to be developed and implemented to provide protection from tort liability.

There have also been concerns that the implementation of new methods would impose new burdens on agencies. It was noted that the MUTCD should provide flexibility for agencies in terms of complying with minimum maintained traffic sign retroreflectivity levels.

This need for maintenance methods was cited often during the FHWA sponsored workshops on minimum levels of in-service retroreflectivity for signs in the summer of 2002.(12) These workshops were conducted to present the most recent research findings on minimum levels of retroreflectivity and to solicit input from public agency officials prior to developing a proposed rule on minimum levels of retroreflectivity. A total of 99 individuals participated in the four invitation-only workshops. One of the most consistent key findings of the workshops was that the public agency participants wanted the MUTCD to provide several methods that could be used to meet the minimum retroreflectivity requirements.

DEFINITIONS OF MAINTENANCE METHODS

A significant portion of the 2002 FHWA workshops on nighttime traffic sign visibility was devoted to discussions of options that are available to agencies to improve the nighttime visibility of signs. Several different terms were used to describe the options, including evaluation methods, assessment procedures, implementation options, and management processes. All of the terms were intended to describe actions that an agency can take to provide a reasonable level of nighttime sign visibility to road users.

There was essentially unanimous agreement among the public sector participants that the MUTCD should not dictate the methods or processes to be used to determine whether signs meet the goal of reasonable nighttime visibility. Instead, the MUTCD should describe various evaluation methods that agencies can choose from to provide reasonable nighttime sign visibility. The ability to choose from several options will allow agencies to adopt a method that best fits the resources and current practices of individual agencies.

Different methods were presented and discussed during the various workshops. Most methods can be divided into one of two categories—evaluation or management methods. Evaluation methods involve some type of assessment of the nighttime visibility of individual signs (e.g., visual inspection or retroreflectivity measurement). Management methods are based on the expected retroreflective life of the overall sign inventory, based on factors such as warranties, demonstrated performance, or control sign assessments. The following accepted methods are described in greater detail in this report.

- **Nighttime Visual Inspection.** The retroreflectivity of an existing sign is assessed by a trained sign inspector following a formal visual inspection procedure from a moving vehicle during nighttime conditions. Signs that are visually identified by the inspector to have retroreflectivity below the minimum levels should be replaced.
- **Measured Sign Retroreflectivity.** Sign retroreflectivity is measured using a retroreflectometer. Signs with retroreflectivity below the minimum levels should be replaced.
- **Expected Sign Life.** The installation date is labeled or recorded when a sign is installed, so that the age of any given sign is known. The age of the sign is compared to the expected sign life. The expected sign life is based on the experience of sign retroreflectivity degradation in a geographic area. Signs older than the expected life should be replaced.
- **Blanket Replacement.** All signs in an area/corridor or of a given type are replaced at specified intervals. This eliminates the need to assess retroreflectivity or track the life of individual signs. The replacement interval is based on the expected sign life for the shortest-life material used in the area/corridor or on a given sign type.

- **Control Signs.** Replacement of signs in the field is based on the performance of a sample set of signs. The control signs might be a small sample located in a maintenance yard or a selection of signs in the field. The control signs are monitored to determine the end of retroreflective life for the associated signs. All signs represented by a specific set of control signs should be replaced before the retroreflectivity levels of the control signs reach the minimum retroreflectivity levels.

Other methods (e.g., sample comparisons, Q-beam methods (illuminating a sign with a spot light during a daytime visual inspection), and visual inspection techniques tied to evaluation distances dependent on sign type and size) were identified in the workshops but were not considered practical or effective in determining the adequacy of nighttime visibility. Workshop participants also indicated that a sign management system could also be used as one of the evaluation methods. However, an evaluation method is a tool that supports a sign management system. A sign management system does not provide a means for evaluating nighttime sign visibility; it provides a means of managing information from one or more evaluation systems used to predict when a sign should be replaced.

The MUTCD minimum retroreflectivity requirements are not intended to imply that agencies must measure the retroreflectivity of every sign in their jurisdictions. The various maintenance methods provide agencies with options that will improve nighttime sign visibility.

The sign retroreflectivity maintenance methods described above are divided into two groups, assessment methods and management methods, as noted in table 3. Agencies have flexibility to adapt these methods for maintaining sign retroreflectivity into existing sign management processes or may upgrade their sign management process by incorporating an approved maintenance method.

Table 3. Retroreflectivity Maintanence Methods.

Assessment Methods	Management Methods
Nighttime Visual Inspections Retroreflectivity Measurements	Expected Sign Life Blanket Replacement Control Signs

COMBINING MAINTENANCE METHODS

Combinations of two or more methods may be viable for some agencies. In addition, agencies are not limited to the proposed maintenance methods. Agencies may develop their own methods using documented engineering studies that demonstrate that deviations are appropriate.

Agencies may combine different methods or parts of different methods to achieve sign retroreflectivity maintenance practices that best fit the agency’s needs and budget. Generally, a combination method would include a management method complemented with an assessment method used to provide supplemental data. This method provides a means to track individual signs but without the need to inspect or measure every sign. Any number of combinations can be implemented to logically integrate with other aspects of the sign management process and best fit an agency’s limited resources. Also note that the proposed methods can be used exclusively with effective results.

One possible combination is the use of a management method with both daytime and nighttime visual inspections. The expected life of a sign is a management method and is based on the age and degradation of the sheeting types used. This management method in combination with daytime visual inspections may allow an agency to track how many signs they have, how old they are, and where they are located. It also provides field crews with a list or summary of deployed signs that can be easily used to note the need for sign replacements or repairs when conducting nighttime visual inspections. The information may be downloaded to electronic devices (e.g., laptop computers or PDAs) to further facilitate field inspections and documentation of sign conditions and replacement needs. Combining the expected sign life management method with both daytime and nighttime visual inspections is one example of adapting methods that meet an agency’s needs.

Another possibility is to combine expected sign life with measured retroreflectivity. Under this method, it is not required to measure the retroreflectivity of all signs. Measurement of a small sample from across a region allows the agency to compare the expected and measured retroreflectivity. The measurements allow the agency to validate, and revise if necessary, the service life of each sign sheeting material and color used by the agency.

In summary, these methods can be used in different ways but will provide a consistent evaluation of the nighttime visibility of in-place traffic signs. Additional details on these methods and their applications are provided in the following chapters.

OBJECTIVES OF SIGN RETROREFLECTIVITY MAINTENANCE METHODS

The intent of the methods is to provide a systematic means for agencies to maintain traffic sign retroreflectivity at or above the minimum levels. The FHWA has determined that agencies that use an approved method to maintain traffic sign retroreflectivity are in conformance with the minimum maintained retroreflectivity requirements established in the MUTCD.

Substantial conformance with the MUTCD Section 2A.09 is achieved by having a method in place to maintain the minimum retroreflectivity levels. Conformance does not require or guarantee that every individual sign will meet or exceed the minimum retroreflectivity levels at every point in time. For example, if an agency chooses to implement the visual nighttime inspection method, there is no guarantee that the retroreflectivity of all signs will be satisfied during the entire period that the signs are in service. Assuming that an agency successfully completes the annual visual nighttime inspections and that signs failing the subjective evaluation or signs rated as marginal are scheduled for replacement or reassessment within a reasonable time period, then there is clearly a period of time when these signs might be below the minimum retroreflectivity levels while the sign is awaiting replacement or reassessment. Having a method in place to maintain the minimum retroreflectivity levels is a valuable way for agencies to prioritize how to spend limited resources on those signs that should be replaced sooner, ultimately contributing to improved safety for the motoring public.

There are other conditions where signs might be rated as being satisfactory while temporarily falling below the minimum retroreflectivity levels. For example, dew and frost on signs have been shown to significantly reduce retroreflectivity.(13) In addition, while research has shown that the visual nighttime inspection is a reasonable method in terms of identifying signs that need to be replaced because of marginal retroreflectivity, the nighttime visual inspection method is not 100 percent reliable.(14,15) When sign inventories are not available for use during visual inspections, it is not unreasonable to miss a small percentage of signs along a densely-signed corridor, especially if a sign was knocked down or missing for some other reason at the time of the inspection. It is also possible that a sign or a group of signs meets the retroreflectivity minimums for a predetermined number of years, but because of factors such as manufacturing defects or inadvertent mishandling during installation, a certain percentage might fall below the minimum retroreflectivity levels sooner than expected.

Regardless of which maintenance method is adopted by an agency, documentation of the sign management process is important in assisting agencies to achieve conformance with the MUTCD standard to maintain minimum retroreflectivity levels of traffic signs. Written procedures ensure that agency personnel properly follow the selected method, while maintenance records provide the agency with a systematic process for sign replacements and justification for the allocation of limited resources. As an example, measurements of traffic sign retroreflectivity might show that certain signs are near or below the thresholds in the table of minimum retroreflectivity levels even before they reach the end of their expected life. The records provide documentation that an appropriate maintenance method was followed and permit the agency to assess and revise, if necessary, the method for a given type or group of signs. As long as an agency has a reasonable method in place to manage or assess its signs and establishes a reasonable schedule for sign replacement as needed, the agency will be deemed to be in conformance.

CHAPTER 3. ASSESSMENT METHODS

This chapter contains information about the evaluation or assessment methods for maintaining traffic sign retroreflectivity. The methods described in this chapter include

- Nighttime Visual Inspections.
- Measuring Traffic Sign Retroreflectivity.

The basic concept of an assessment method is that the condition of each individual sign is assessed or evaluated on a periodic basis. The MUTCD does not set specific intervals, but many agencies currently assess their signs every one to two years.

VISUAL NIGHTTIME INSPECTIONS

Visual inspections are perceived to be the most likely means to find nighttime visibility problems with signs. Using this approach, it is possible to assess more than just the retroreflectivity of a sign. Damage, obstructions, poor placement, and other factors that might detract from the nighttime visibility of the sign can be observed. The MUTCD currently includes language that encourages agencies to undertake periodic daytime and nighttime visual inspections. Many agencies already perform some type of periodic sign inspection, although not all inspections are performed at nighttime. This method requires a minimal investment of resources on the part of the agency, although there is a need for a record-keeping system for inspection data and the potential for higher labor costs where overtime pay is required. While visual inspections will reveal night visibility problems not discernable under any other method, they are subjective and hence more difficult to tie to a benchmark value of retroreflectivity. Agencies using visual inspections must establish procedures to provide consistency in inspections. This implies the need for training programs and certification of inspectors to assure consistency of inspections. Inspection procedures should address the type of vehicle used, type of headlamps on the inspection vehicle, headlamp aiming, and age and visual acuity of the inspector(s).

Background

Probably the most common type of sign maintenance program is the visual inspection method. Guidelines have been available for at least 50 years concerning the details of how to conduct a proper nighttime sign inspection.[16,17] While there are some concerns about the reliability of the visual nighttime inspection, research has shown that trained inspectors can do a reasonable job of determining which signs need to be replaced because of inadequate retroreflectivity.[14,15]

The visual inspection technique uses trained personnel to observe traffic signs during the nighttime to assess the overall appearance of a sign and determine if it meets the required minimum retroreflectivity level. The observation is typically done through the windshield of the vehicle at or near the speed limit of the roadway.

The key to this method is having trained inspectors. While there is no nationally-recognized training course or certification for sign inspectors, agencies should provide some form of training before sign inspections are performed. One way to perform the training is to have the inspectors observe sample signs at a variety of known retroreflectivity levels before conducting the inspections. Training helps facilitate an inspector's ability to discern sign retroreflectivity levels that are at the minimum levels prior to conducting inspections. Preferably, there should be sample signs that are at or near the minimum retroreflectivity levels associated with each sign type and color. The inspector should view the sample signs under similar conditions to those under which inspections will be performed. This includes using the appropriate vehicle and placing the sample signs at typical positions that will be encountered during an inspection. For this method to be effective, the training must prepare the inspector in advance, using correct sample signs that represent retroreflectivity levels at or near the MUTCD minimum retroreflectivity levels.

Procedures

The usual method of inspecting signs at night is to use a two-person crew. While the driver focuses on the driving task, the passenger evaluates the signs and records the appropriate information. An alternative to a two-person crew is to use one person with a tape recorder or camcorder. If an inventory is available, signs that have been knocked down or missing for some other reason can be identified during the nighttime inspection. If no inventory exists, an inventory of existing signs can be created while conducting the nighttime inspection, but it may not account for missing signs. A nighttime inspection procedure can be performed without a sign inventory.

The nighttime visual inspection method should only use the low-beam headlamps of the vehicle as the source of illumination for the signs. The interior light of the vehicle should remain off to the extent feasible. The inspection should be performed at highway speeds and from the travel lanes and not the shoulder. As the vehicle approaches the sign, the sign's overall appearance in terms of brightness and legibility is assessed. Usually the sign is given a rating defined by the agency. At a minimum, the scale should include three designations: good, fair, and poor. The inspector records the information for each sign and the rating that it is given. Signs rated as poor should be scheduled for replacement as soon as possible. Depending on the inspection schedule, signs rated as fair can be noted as requiring attention during the next set of scheduled inspections or can be identified for additional assessment, such as measurement at a later date using a hand-held retroreflectometer.

The vehicle and inspector combination should be selected to provide a conservative estimate of sign retroreflectivity. The increased sales of pickup trucks and sport utility vehicles, which result in larger observation angles, make these types of vehicles appropriate for use in many regions. Relatively new vehicles, with visually/optically aimable (VOA) headlamps, should be considered. Ideally, the inspector should be older, with nighttime visual capabilities similar to older drivers. The vision of the inspector should be tested to ensure that it is within the legal limits of the State. It is important that an agency develop consistent guidelines to decrease the subjectivity of inspections. For instance, some items to consider are procedures to clean the headlamps and windshield before each night of inspections and to periodically check the headlamp aiming. A procedure to check the headlamp aim of VOA headlamps is provided in table 4.

Table 4. Headlamp Aiming Procedure.

What you will need:

- ✓ A level area with a distance of approximately 7.625 m (25 ft) plus the length of the vehicle from a flat lightly colored wall
- ✓ A tape measure
- ✓ Masking tape

Instructions:

- ❑ Park the vehicle so that the headlamps are precisely 7.625 m (25 ft) from a flat lightly colored wall. The vehicle should have at least ½ of a tank of gas and should be loaded as it would be when inspecting signs. This includes the weight of the driver (and passenger present).
- ❑ Measure the exact middle of both the windshield and rear window, and mark them with strips of tape, creating vertical centerlines, front and rear.
- ❑ Standing behind the car, sight along the centerlines, and have an assist mark the position of the vehicle centerline on the wall with a vertical strip of tape.
- ❑ Measure the distance between the vehicle centerline and the headlamp lenses. Mark that distance to the right and left of the centerline on the wall with vertical strips of tape.
- ❑ Measure the height of each headlamp from the ground (measuring to the center of the lens). Using those measurements, place horizontal strips of tape on the wall where the vertical strips have been applied. There should now be two crosses on the wall, with centers that correspond to the center of each headlamp lens.
- ❑ For headlamps with a left-side cutoff (VOL), mark a horizontal line that is 53.34 mm (2.1 inches) below the headlamp centers with a horizontal strip of tape. For headlamps with a right-side cutoff (VOR), mark a horizontal line that runs through the headlamp centers.
- ❑ Turn the vehicle headlamps on low beam. The left edge of the bright spots on the wall should just touch the vertical bars of the crosses. The top edge of the strongest gradient of light should just touch the horizontal line. Adjust the headlamp aim per manufacturer's instructions, if required.

Probably the most important element of the nighttime inspection is documenting the process and results. This can be done with a voice or video recorder, or even with paper and pencil. Whichever method is selected, it is important that inspections are properly documented and archived to provide tort protection.

Current Practices

Visual nighttime inspections are typically used in conjunction with a signage replacement schedule to make sure that the signs are legible and to find signs that may have been passed over or accidentally skipped during the last replacement schedule. Inspections are usually performed every one to two years and rotate between predefined sections of roads under the agency's jurisdiction. The inspection plans should include specific routings to ensure full coverage of the road network and that the inspections can be safely conducted with the levels of traffic on the road. A variety of practices exist for documenting inspection results and initiating actions to replace signs that are at or near the minimum levels.

Concerns

One concern associated with nighttime visual inspections is that it is the most subjective of all the methods. Another concern is funding overtime pay to conduct the inspections during late-evening or early-morning hours. It is also important that inspectors are properly trained.

Linking Nighttime Visual Inspections to Minimum Retroreflectivity Levels

Minimum retroreflectivity levels are incorporated into this method by training the inspectors and using procedures that allow them to correlate their observations through the use of sample signs. A good practice is for inspectors to observe the sample signs prior to each inspection run. The use of appropriate sample signs at or near minimum retroreflectivity levels is a key element to training that links the nighttime visual inspection method to the minimum retroreflectivity levels.

Advantages and Disadvantages

One of the major benefits of using the visual inspection method is that it has the least administrative and fiscal burden of all the methods. Many agencies already perform some type of periodic sign inspection, although not all inspections are performed at night. This method also has a unique feature in that the signs are viewed in their natural surroundings. Thus, the overall appearance of the sign and the ability of the sign to provide information to the driving public can be assessed.

Another advantage of the visual inspection method is that it has the lowest level of sign replacement and sign waste. Only those signs identified as needing to be replaced because of low retroreflectivity levels are replaced, assuming that the inspection frequency is appropriate. With management methods, it is probable that some signs will be replaced before their full life is achieved. This may imply that the visual inspection method (as compared to the measured retroreflectivity method) maximizes sign life.

While this method may be more subjective than other methods, research has shown that trained observers can reasonably and repeatedly detect signs with marginal retroreflectivity. There is some risk involved while doing these inspections, particularly if the driver is also the evaluator and recorder. Ideally, nighttime inspections should be conducted with two people for safety reasons.

MEASURED SIGN RETROREFLECTIVITY

In general, there are two ways that sign retroreflectivity can be measured in the field: with hand-held contact instruments or with non-contact instruments. Contact instruments require the measurement device to be in physical contact with the sign surface. Non-contact instruments, which measure the retroreflectivity from a distance, include both a hand-held device and vehicle-based systems. The use of the measurement method as an exclusive process to maintain sign retroreflectivity has not historically appealed to agencies, as will be discussed in the following sections. However, when combined with another method, the measured sign retroreflectivity method adds an element of accuracy to the overall program. This combination of methods may maximize maintenance budgets and provide additional protection from tort claims.

Background

There are several commercially available hand-held retroreflectometers that can be used to measure sign retroreflectivity. While the contact instruments are believed to provide relatively low levels of uncertainty for a given measurement, using contact instruments can be time consuming. Non-contact devices offer flexibility and speed-up the measurement process, but the trade-off is a higher level of uncertainty. The uncertainty associated with field measurement of sign retroreflectivity has not been well established. ASTM procedures for the measurement of sign retroreflectivity require the averaging of multiple measurements on the face and legend of the sign. The selection of the measurement points and the calibration of the device can lead to different results, even when measuring the same sign. This can create an issue if there are small differences between measured values and the required minimum levels—while the uncertainty in the precise value may not be significant from a performance standpoint, it has some potential to create tort liability for marginal signs.

More information about retroreflectometers can be found on the following Web sites:

Contact Devices, Hand-Held

- Delta Retrosign GR3, http://www.flinttrading.com.
- Roadvista 922, http://www.roadvista.com.
- Zehntner ZRS 5060, http://www.zehntner.com/html/download/prospekt_zrs5060_d_e.pdf.
- Mechatronic RC200, http://www.mechatronic.de/04traffic/en/01/rc2000.html.

Non-Contact, Hand-Held

- Impulse RM, http://www.pwsglobalinc.com.

Non-Contact, Mobile

- Mandli Digilog road systems, http://www.mandli.com/.

Note that the FHWA does not endorse the use of any specific instrument. While the above list is, to the best knowledge of the authors, complete as of the date of publication, other instruments may be available or may become available in the future. Each agency is encouraged to review the specifications for the various instruments and determine for themselves which instrument is most appropriate for their application.

Procedures

Measuring retroreflectivity using a contact instrument should be performed as specified in ASTM Standard Test Method E1709-00e1, which requires a minimum of four retroreflectivity measurements to be taken of the sign background and legend, if applicable. The four measurements for each color are averaged to obtain an overall measurement of the retroreflectivity for each color on the sign. These values are compared to the minimum retroreflectivity values to determine whether or not the sign should be replaced.

Hand-Held Contact Instruments

One important distinction needs to be made between the hand-held contact instruments: ASTM E1709 describes two types of sign retroreflectometers: point instruments and annular instruments, which are defined in the test method as follows:

> "The instrument may be either a "point instrument" or an "annular instrument," depending on the shape of the receiver aperture. Point and annular instruments make geometrically different measurements of R_A, which may produce values differing on the order of 10 percent. Both measurements are valid for most purposes, but the user should learn the type of his instrument from its specifications sheet and be aware of certain differences in operation and interpretation. For both instrument types, the "up" position should be known. The point instrument makes an R_A measurement virtually identical to an R_A measurement made on a range instrument following the procedure of Test Method E810. The annular instrument makes an R_A measurement similar to an average of a great number of R_A measurements on a range instrument with presentation angle (γ) varying between -180 ° and 180 °."

The geometries for the two types of hand-held contact instruments are illustrated in figure 1, while figure 2 provides an illustration of the instrument layout.

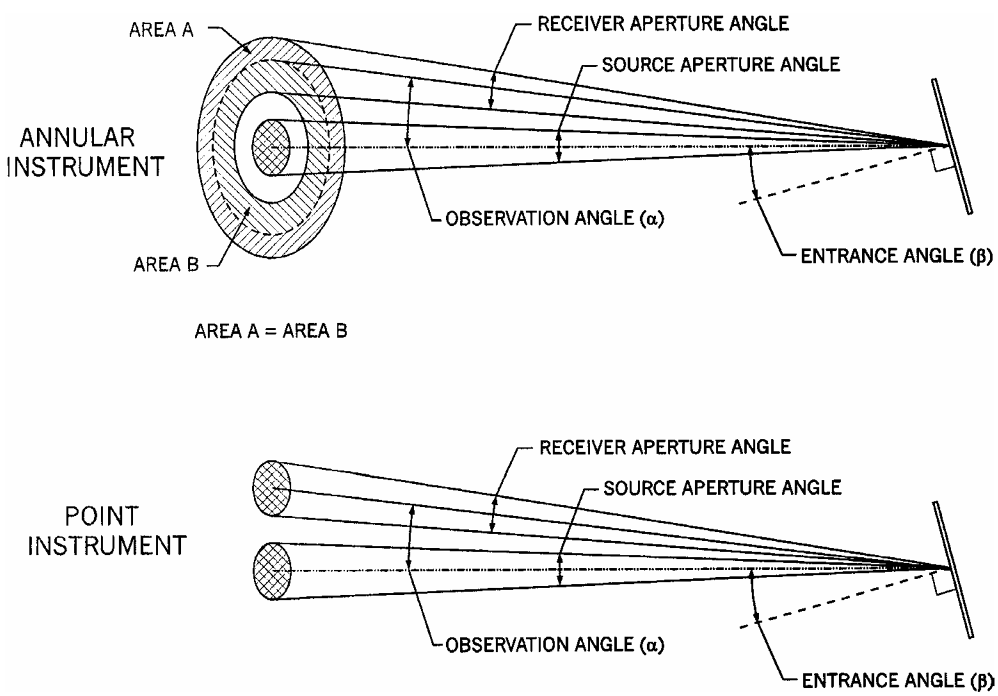

Figure 1. Annular and Point Aperture Instrument Angles. [1]

[1] Reprinted, with permission, from ASTM E1709-00e1 Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM (http://www.astm.org).

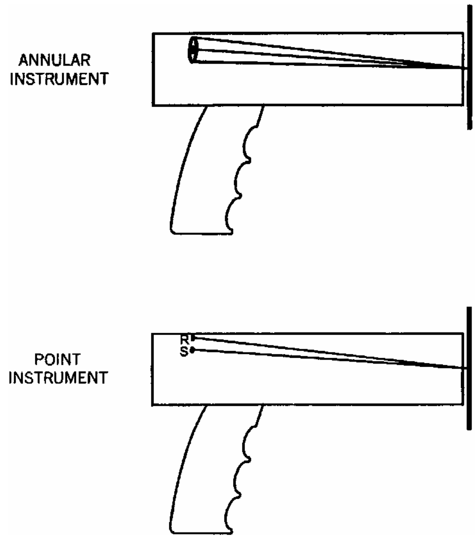

Figure 2. Upright Optical Schematics.[2]

Differences in Point and Annular Instrument Measurements

Glass bead sheeting materials tend to be rotationally insensitive. Therefore, point and annular instruments should produce similar R_A values for these materials. The R_A values for prismatic sheeting, however, are rotationally sensitive, and the R_A values produced by point and annular instruments can differ on the order of 10 percent, with differences of up to 25 percent possible. Annular instruments cannot accurately gauge how the R_A of prismatic sheeting varies with rotation angle.

Current Practice

Few agencies have reported making retroreflectivity measurements of traffic signs on a regular basis. Most of those agencies use the retroreflectivity measurements to supplement visual or other inspection methods. The remainder use measured retroreflectivity values from a sample set of signs as an assessment of their total sign inventory.

There are private companies that specialize in retroreflectivity measurements. These companies offer retroreflectivity measurements for both signs and pavement markings, but the majority of the work that has been performed by private companies pertains to retroreflectivity measurements of pavement markings.

Concerns

The main concern with the measured sign retroreflectivity method is that retroreflectivity only accounts for one aspect of a sign's appearance. Other factors should be considered when determining whether or not a sign is adequate for continued use at a particular location. These factors include ambient light levels, presence of glare, location relative to the road, and the

[2] Reprinted, with permission, from ASTM E1709-00e1 Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM (http://www.astm.org).

complexity of the visual background. A sign that is acceptable in a rural environment may not be acceptable in a complex urban environment.

Another concern with this method is the amount of time it takes to measure the retroreflectivity of a traffic sign using hand-held devices. Given the current methods and technology available to obtain a sign's retroreflectivity, the time commitment required to take retroreflectivity readings of all signs within an agency's jurisdiction may be labor intensive and cost prohibitive.

Linking Measurements to Minimum Retroreflectivity Levels

This method uses measured retroreflectivity as the basis for the decision of whether or not a sign meets the required minimum level of retroreflectivity. The measured retroreflectivity values are compared to the minimum retroreflectivity levels specified in the MUTCD. A sign should be scheduled for replacement if the measured retroreflectivity is at or very close to the minimum required level. This method provides the most direct comparison of the sign's in-service retroreflectivity relative to the minimum maintained retroreflectivity levels.

Advantages and Disadvantages

Measured retroreflectivity provides the most direct means of monitoring the maintained retroreflectivity levels of deployed traffic signs. This removes all subjectivity that exists in other methods. However, a limit must be established on how close a sign's retroreflectivity levels can be to the required minimum levels before they are replaced. Measurement uncertainty and the variance between the retroreflectivity at the prescribed measurement geometry versus the retroreflectivity at the actual observation geometry may result in a sign that meets the minimum requirements but does not meet the needs of the driver, and vice versa.

The main disadvantage of using this method is that measuring all of the signs in a jurisdiction is time consuming. Measured sign retroreflectivity may be best used to support one of the other methods or as a means of evaluating marginal signs. Another disadvantage is that using the retroreflectivity of the sign as the only indicator of whether or not a sign should be replaced may end up neglecting other attributes of the sign's overall appearance. Other factors should be considered, including the overall appearance and legibility of the sign, as well as environmental concerns, such as areas with high levels of visual clutter or glare, that may require a brighter sign. Agencies need access to instruments and trained personnel to use this method.

CHAPTER 4. MANAGEMENT METHODS

This chapter describes the management methods that can be used for maintaining traffic sign retroreflectivity. The methods described in this chapter include

- Expected Sign Life.
- Blanket Replacement Method.
- Control Sign Method.

EXPECTED SIGN LIFE

In this method, signs are replaced before they reach the end of their expected service life. The expected service life is based on the time required for the retroreflective material to degrade to the minimum retroreflectivity levels. The expected service life of a sign can be based on sign sheeting warranties, test deck measurements, measurement of signs in the field (control signs) and measurement of signs taken out of service, or information from other agencies. The key to this method is being able to identify the age of individual signs. This is often accomplished by placing a sticker or other label on the sign that identifies the year of fabrication, installation, or planned replacement or by recording the date of installation in a sign management system. Various approaches or algorithms can be used to trigger an indication of the need to replace a sign. For example, one software system uses sign material type, color, age, and direction the sign faces in a model that predicts the level of retroreflectivity at any point in time. When the minimum levels are approached, the sign is flagged for replacement. The process must, however, be geared to flag signs that need replacement early enough to assure that the process of physical replacement can be completed before the signs drop below the minimum retroreflectivity levels.

Procedures

Although there are variations to this method, the basic idea is that the installation date of every sign in an agency's jurisdiction is known, along with the type of retroreflective sheeting material used on the sign face. It is also necessary to define an expected sign (i.e., service) life for each type of retroreflective sheeting material. This can be done for individual signs or as a general parameter for the types of material used by the agency. Other information may also be of interest to the agency such as sign color, direction the sign is facing, and sign construction (silk-screening versus electro-cut (EC) film). This information is used in a systematic manner to "flag" signs that need to be replaced before their sign life expires.

One way to use this method is through a computerized sign management system to keep track of an agency's sign inventory and periodically extract information on signs that are reaching the age at which they need to be replaced. The degree of sophistication of the sign management system will dictate the options available to the agency. For example, most systems can generate lists of signs needing replacement, but some allow specific categories of sign type, size, or color to be focused upon. These systems may be able to generate individual work orders for each sign that needs to be replaced or can group replacements in a manner that provides an effective work schedule for sign crews.

If an agency has a computerized sign management system, it should be possible to query the sign database at regular intervals for a list of signs that are nearing the end of service life. Actual readings of sign retroreflectivity can be taken to determine if the degradation is occurring as expected. If the degradation is not occurring as fast as expected, then signs of that type could be left in the field longer (and an update to the planned replacement date subsequently made in the database). Conversely, if the deterioration is occurring faster than expected, the signs can be scheduled for replacement sooner. Monitoring changes in degradation can help ensure better nighttime visibility and increase the overall life cycle of an agency's signs, resulting in cost savings.

Another way this method can be used is by placing an installation or replacement date sticker on each sign to allow field crews to know when specific signs reach their replacement age. If a sign is found to be older than indicated by the maximum life noted on the sticker, then the sign should be replaced. This method can be time consuming if signs along a roadway vary significantly in age, but it can be executed during the day and requires no inspection or measurement of the sign. A complication of this method is related to the placement of the date stickers. When placed on the front of the sign, field crews can more readily view the date information. However, the information must be limited so as not to distract from the message on the sign. More information can be included on stickers placed on the back of the sign, but it is harder for field crews to see this information as they drive by, particularly on wide roadways. Figure 3 shows the Wyoming coding system that can be seen from the front of the sign. The number indicates the year the sign was installed. For instance, the stop sign was installed in 1995. Wyoming uses a 10-year replacement cycle that allows the Wyoming agency to use a one-digit coding system. (Note: The photograph was taken before 2005.) Minnesota uses a color-coded sticker on the back of the sign, as shown in figure 4, with a different color each year to make inspections easier.

Figure 3. Examples of Wyoming DOT Signs.

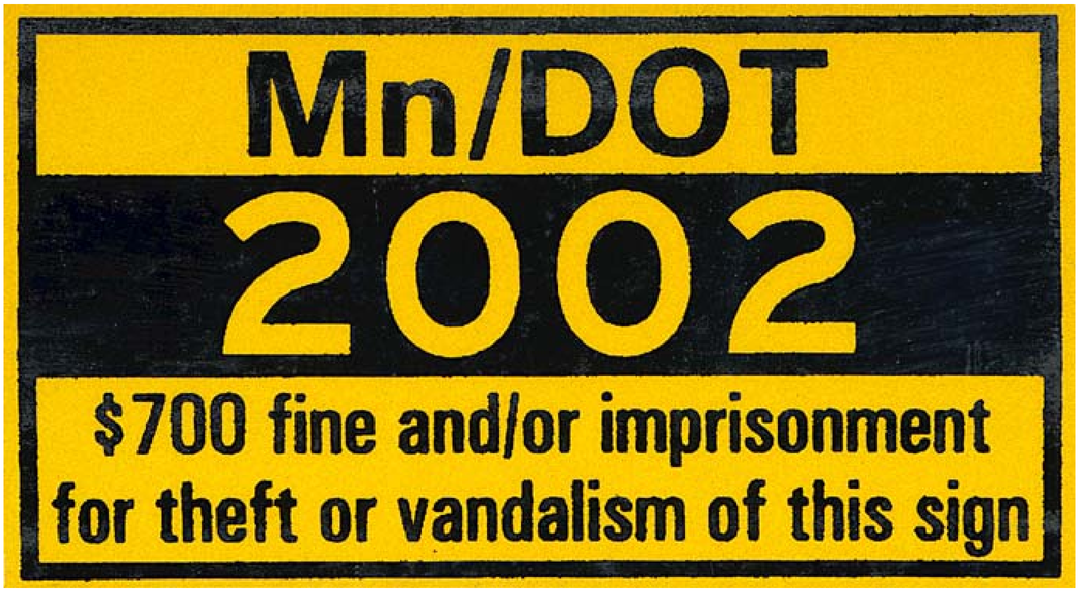

Figure 4. Example of Minnesota DOT Sign Sticker.

Current Practice

The use of expected sign life as a maintenance method is widely used because of its ease of implementation. Most agencies use the warranty period provided by the manufacturer to determine when a sign should be replaced. However, some agencies, like Indiana, are beginning to extend their expected sign life levels beyond the warranted sign life as a result of research documenting the durability of sign materials in their area.[18] This may create some complexity in sign management, as the expected sign life will vary across a jurisdiction depending on the geographic location of the sign, the amount of direct sun exposure, and other environmental factors that affect service life. The use of a single value for expected service life might result in some signs failing to meet the minimum maintained retroreflectivity levels prior to scheduled replacement or might result in replacement of signs that exceed the minimum levels.

Delaware, Kansas, Maine, Missouri, and North Dakota all use a 10- to 12-year life cycle for all of their beaded high-intensity retroreflective materials (as of 2005). Some agencies such as Indiana[18], Michigan, and North Carolina[19] are learning that they can expect their in-service life expectancy to be 15 years for beaded high-intensity materials.

Concerns

The main concern with this method is that there are little data on how different types of sheeting deteriorate over time in a given climate. It can be a complex process to determine how long signs of a certain sheeting type and color will last in a given region of the country. Also, there are no definitive results on the role that the orientation of the sign face plays in the deterioration of the sign and whether or not signs facing different directions deteriorate at significantly different rates. While there have been many studies, these studies do not come to the same conclusions about the relationship between sign face orientation and deterioration rates. (See references 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, and 31.)

One of the easiest ways to assign expected sign life to retroreflective sheeting materials is to use the manufacturer's warranty. However, these warranties obviously include a certain factor of risk on the part of the manufacturer and therefore are often conservative. They may also vary depending on the region of the country. In general, however, it can be expected that retroreflective sheeting materials will have a warranty provided for the ASTM Type-designated materials as shown in table 5. Additional information on sign sheeting durability can be found in several research reports. (See references 18–31.)

Table 5. Typical Warranty Life.

ASTM D4956 Type	Years of Warranty*
I and II	7
III and IV	10
VII, VIII, IX, X	12
* May be different for fluorescent sheeting materials	

Linking Expected Sign Life to Minimum Retroreflectivity Levels

The minimum retroreflectivity levels provide the initial basis for the expected life criteria, but an understanding of the actual degradation rates of in-service signs is required to set appropriate triggers as retroreflectivity levels approach the minimum requirements. Degradation rates differ by region of the country, type and color of material, and orientation. Furthermore, under this method, the actual retroreflectivity of a sign is not assessed—only the age of the sign is monitored.

There is a potential need to gather sample data on the true service life of signs to adjust the expected life measures. Some agencies accomplish this by the measurement of a sample of the removed signs; some monitor the performance of a small number of signs; and others measure the retroreflectivity of in-service signs with known installation dates.[19]

Advantages and Disadvantages

This method requires that agencies track the installation date of their signs. For the field replacement approach to this method, there is the benefit of associating the condition of a sign to its age. The use of a computerized sign management system may eliminate the need for a date sticker, but it also limits the means that may be used to analyze actual service lives because of the need for bar-code reading equipment or other technology-dependent equipment that might be used to code information on a sign.

The expected sign life method allows agencies to help develop local service life requirements based on actual end-of-service-life retroreflectivity measurements and comparisons to minimum required levels. These comparisons can provide useful information on service life under local conditions, product performance, sign fabrication processes, and analysis of replacement strategies. This method requires that the type of sheeting used to fabricate a sign be known. Other pertinent information may also be necessary to take advantage of sophisticated sign life prediction algorithms.

One drawback to this method is that it can be fairly time consuming to check date stickers if the stickers are not easily viewable or identifiable on the sign. Another possible difficulty relates to marking signs that need to be replaced, although immediate replacement is possible for some sign types. If an agency uses a sign management system and functions with the use of portable computers in the field, the inspectors can easily note the signs that need to be replaced, and even generate work orders.

BLANKET REPLACEMENT

The blanket replacement method is essentially the expected sign life method executed on a spatial or strategic basis. On a spatial basis, all the signs in a specific area or corridor get slated for replacement at the same time, when the effective service life is reached. On a strategic basis, all the signs of a specific type get slated for replacement at the same time. Depending on the size of the jurisdiction, it may be possible to plan sign replacements that consider both geographic and strategic criteria. The blanket replacement is being used by various agencies around the country such as the City of Glendale, AZ.

This method is probably the simplest of the management methods in that tracking the age of individual signs, either by physical labeling or in a database, is not necessary. It is only necessary to maintain a record of when the blanket actions were undertaken and when they need to be repeated. Usually this method is repeated after a set number of years, depending on the expected life of the signs.

Procedures

At set time periods, a sign maintenance crew will go to a specific area or corridor and replace all the designated traffic signs under its jurisdiction. This might be done such that regulatory signs are replaced in one cycle, warning signs in another cycle, and guide signs in a third cycle. The time interval between replacements is usually based on the expected sign life as discussed in the previous section. Under this method, all signs are replaced regardless of the amount of time they have been in the field or the condition at the time of replacement. Blanket replacements can be scheduled to coincide with major roadwork or repaving, resulting in the least impact on traffic. This is especially beneficial on routes with high traffic volumes.

Current Practice

This maintenance method is popular with State DOTs. Of the agencies that were contacted and that use a blanket replacement method, most replace their Type I signs every 7 to 10 years; Type III signs every 10 to 15 years; and Types VI, VIII, and IX signs every 15 years. The vast majority of the agencies contacted use Type III sheeting for the majority of their traffic signs, although some agencies are testing the use of Types VII, VIII, and IX for use on a wider scale. Some agencies currently use the microprismatic materials for signs that they believe require higher visibility.

Replacement time depends on the region of the country as well as on past experience of how long signs last in the field. For example, Maine, Kansas, and New Hampshire replace signs with Type III sheeting every 10 years, while Minnesota replaces Type III signs every 12 years and

Michigan every 15 years. Minnesota also uses Type IX sheeting on guide signs and replaces these signs every 15 years.

Concerns

One of the issues with this method is that the replacement times can vary depending on the region of the country in which the agency is located, or even across a jurisdiction for large agencies. The replacement time also depends on the types of sheeting that are used to make the agency's traffic signs. Therefore, an agency needs to have relevant data on the in-service life of all the sheeting materials it has in the field. Another concern is that this method potentially wastes resources by removing signs before their useful life has been reached. This is particularly true where signs have been added or replaced in an area after the last replacement cycle. When the replacement cycle comes around, these signs will be replaced regardless of their age. They can be reused if handled properly, but that would require that each sign that is replaced be inspected to determine the amount of useful sign life remaining.

Linking Blanket Replacement to Minimum Retroreflectivity Levels

The minimum retroreflectivity levels provide the initial basis for the expected life criteria, but an understanding of the actual degradation rates of in-service signs is required to set appropriate triggers as retroreflectivity levels approach the minimum requirements. Under this method, retroreflectivity levels of signs are not measured, and opportunities are limited for capturing data that may be useful in adjusting service lives, trigger points, or sign maintenance strategies.

Advantages & Disadvantages

The major benefit of using this method is that all signs are replaced; there is a low likelihood of a given sign being skipped over or not being replaced. This ensures that all replaced signs are visible and meet minimum retroreflectivity levels.

The major drawback to this method is the potential amount of waste than can be generated if signs that are relatively new are removed during a normal replacement cycle. This can be particularly expensive when a blanket replacement method is first implemented. Follow-up replacement cycles can also be wasteful if signs are replaced between the expected service life periods because of knockdowns, graffiti, etc.

CONTROL SIGNS

The control sign method is based on measurements made of a subset of signs that represent an agency's inventory. The subset of signs represents a population of signs made with the same material for which the retroreflectivity performance over time is monitored by actual measurements. As the retroreflectivity levels of the control signs approach the minimum levels, it triggers action to begin replacement of the entire associated population. The control signs can be located at one or more of the agency's maintenance yards or can be traffic signs that are deployed at various locations in the jurisdiction. The control signs are measured periodically to monitor actual degradation of retroreflectivity. This method requires only the management of the control sign information and the retroreflectivity measurements of those signs over time.

Procedures

The use of this method requires the installation of signs in a maintenance yard or the definition of specific control signs from the population of deployed signs. Periodic measurements of control signs are made following ASTM E1709 or other accepted procedures. Measurements or other observations are tracked over time to monitor changes in retroreflectivity and nighttime visibility. Once these signs, as a whole, start to approach the minimum retroreflectivity levels, all the traffic signs in the field that these control signs represent are replaced.

Current Practice

None of the agencies contacted reported using this method to maintain their traffic signs. However, some agencies do take retroreflectivity readings on a sample set of signs to estimate how the overall sign population is performing. This is used primarily as a verification method for agency sign management polices and practices.

Concerns

The effectiveness of this method is dependent upon the size of the control sign sample. The larger the sample, the better the estimation of the retroreflectivity levels of the sign populations it represents. There is no specific guidance on the number or percentage of the population the sample represents. However, a minimum of three signs per type of sheeting and color should be monitored.

Another question relates to how often a set of control signs is needed. Each new sign material or deployment of a major product order would warrant a set of control signs, as there are likely to be differences in retroreflectivity performance. It may be appropriate to install controls when new sign fabrication processes are implemented or other major changes in the sign management process occur. It may also be appropriate for a large agency that deploys signs continually to set up control signs as materials age on the shelf and personnel change. Too short a time period between adding control signs may cause the agency to have a large number of control signs to monitor, which negates the simplicity of this method. Too much time between control signs could result in errors estimating the service life of signs installed in the time interval between the control signs.

Another consideration is how often the control signs should be checked for their retroreflectivity levels and appearance. If the time interval between measurements is too short, then this may needlessly waste time and personnel resources. On the other hand, if the time interval is too long, signs may be left in the field that are not adequate for continued use and may pose a possible safety risk. An annual inspection of the signs, including retroreflectivity measurements, may be appropriate.

Linking Control Signs to Minimum Retroreflectivity Levels

The control signs must be measured at given intervals with a retroreflectometer to determine how they are performing. These values are then compared to the minimum retroreflectivity levels in order to trigger sign replacement actions. The precise retroreflectivity levels of the majority of deployed signs are not known using this method.

Advantages and Disadvantages

The main benefit of this method is that it is not nearly as labor intensive as taking retroreflectivity readings on every sign in an agency's jurisdiction. Because a sample set of signs is used to monitor the retroreflectivity levels, it is easier and less labor intensive to get an estimate on how the traffic signs, represented by the control signs, are performing in the field. Another benefit of using this method is that signs that do meet the required minimum retroreflectivity levels are not removed prematurely, allowing for an efficient use of the signs and their material. This may be particularly advantageous when the life of a new sign material exceeds the warranties provided by the manufacturer.

This method requires agencies to have the capability to measure the retroreflectivity of the control signs. Without an appropriate sampling process, the control signs may not be representative of the larger sign population they are intended to represent. This could lead to replacing signs that do not need replacement or not replacing signs that do need replacement. Therefore, agencies must evaluate the number of signs of each type within their jurisdiction and establish guidelines on the number of control signs that are needed to appropriately represent signs in the field.

APPENDIX A. ESTABLISHMENT OF MINIMUM MAINTAINED TRAFFIC SIGN RETROREFLECTIVITY LEVELS

Earlier versions of the MUTCD (in Section 2A.22) have stated, “All traffic signs should be kept properly positioned, clean, and legible, and should have adequate retroreflectivity.” However, the MUTCD did not define what was meant by “adequate retroreflectivity” until recently. While the ASTM Types have been used to specify the types of materials that agencies use, there were no criteria in the United States for “maintained retroreflectivity.” This need for common benchmarks to serve as the criteria for maintaining nighttime traffic sign visibility performance and to link it to sign maintenance processes was recognized in the late 1980s. Since then, considerable efforts have been devoted to developing maintenance criteria that can be used to assess the nighttime performance of traffic signs. These efforts have been based upon retroreflectivity, a convenient surrogate measure of nighttime visibility. This chapter describes the work that has been completed to establish minimum maintained traffic sign retroreflectivity levels. In addition, information relevant to the application of the minimum maintained retroreflectivity levels is provided.

HISTORICAL BACKGROUND

The establishment of minimum maintained traffic sign retroreflectivity levels (also referred to as end-of-service-life values) is one of the latest steps in the evolution of providing a safe and efficient road transportation system. The progression of this concept in the United States was accelerated in 1984 when the Center for Auto Safety (CAS) petitioned the FHWA to establish retroreflectivity standards for signs and markings.(32) Congress then directed the Secretary of Transportation in 1992 to revise the *Manual on Uniform Traffic Control Devices* to include “a standard for a minimum level of retroreflectivity that must be maintained for pavement markings and signs which apply to all roads open to public travel.” (33)

Even before the CAS petition for retroreflectivity standards, the FHWA had an active research program addressing the nighttime visibility requirements of traffic control devices. This research program continued through the 1980s and into the 1990s, resulting in several research reports (see references 34, 35, 36, 37, and 38.), and culminating in 1993 with research recommendations for minimum in-service sign retroreflectivity levels.(39, 40) The minimum retroreflectivity levels were distributed for review and comment among highway agencies, and several national workshops were held. Concerns about the levels and the associated impacts of implementing them became apparent. In 1995, a research effort was funded to revise the initial 1993 levels and to assess the impacts of the requirements on State and local agencies. The research efforts resulted in a pair of reports that were published by the FHWA.(41, 42) The revised 1998 set of minimum levels was presented in these reports.

The most evident change of the 1998 revisions was the removal of minimum levels for overhead signs because of significant variability associated with headlamp luminous intensity directed toward overhead signs. As the 1998 revised levels were being finalized, the Federal Motor Vehicle Safety Standard Number 108, “Lamps, Reflective Devices, and Associated Equipment” (FMVSS 108) was revised so that vehicle owners could easily aim their headlamps and therefore reduce the variability associated with headlamp aim. (FMVSS 108 is the document that sets the minimum and maximum luminous intensities for headlamps, headlamp mounting heights, and standardization of headlamps on *new* vehicles sold in the United States.) Because of these changes, the FHWA sponsored additional research to develop minimum in-service retroreflectivity levels for overhead and street name signs, which were not accounted for by the initial 1993 or revised 1998 levels. The research for overhead and street name signs was completed in early 2001.[(43)] Although the overall approach was different than earlier research related to minimum retroreflectivity levels, several of the same assumptions were maintained. One of the significant contributions of the overhead and street name sign research was a demonstrated need to update some of the fundamental assumptions associated with the earlier development of minimum in-service retroreflectivity levels. From early 2001 until 2003, research continued on the development of updated minimum maintained traffic sign retroreflectivity levels.

It should also be noted that in late 1998, the FHWA was close to issuing a proposed rule on minimum levels of sign retroreflectivity when the Board of Directors of the American Association of State Highway and Transportation Officials (AASHTO) requested that the FHWA delay any future action of minimum retroreflectivity levels until an AASHTO task force could review the proposed minimum requirements and their impacts on highway agencies. The AASHTO Standing Committee on Highways created the Special Task Force on Retroreflectivity in 1999, and it included representatives from Federal, State, city, and county transportation agencies, plus industry, research, and private sector entities. The efforts of the task force led to a resolution that was adopted by the AASHTO Board at its December 2000 meeting. The key points of the resolution were

- Traffic signs should be visible at night.
- Processes are needed for agencies to determine signs that are visible at night.
- The processes used to provide sign visibility at night should not impose undue burdens on transportation agencies.
- Agencies should be able to choose from several different processes that can be used to provide sign visibility at night.
- Minimum visibility requirements should be simple and unambiguous so that they can be easily and properly applied.
- Minimum retroreflectivity values should not be included as part of the MUTCD.
- Agencies should have six years to implement the methods.

TECHNICAL BACKGROUND ON RETROREFLECTIVITY LEVELS

A. 1993 MINIMUM LEVELS

The initial set of minimum retroreflectivity levels published in 1993 was derived from analyses based upon a theoretical computer model called Computer Analysis of Retroreflectance of Traffic Signs (CARTS).[39] The CARTS model is comprised of several sub models that work in series to determine retroreflectivity needs based on user selected inputs. The first sub model determines the minimum distance at which a sign must be legible in order for a motorist to respond appropriately and safely. This distance is termed the Minimum Required Visibility Distance (MRVD) and is the sum of distances associated with the following factors: detecting the sign, recognizing or reading the sign, deciding on the appropriate action, initiating the response, and completing the required maneuver (depending on the sign message, the latter factors may not be needed).

Using the computed MRVD value, the next sub model estimates the threshold legibility luminance needed for the sign. The major componenet of this sub model is a visibility model called PCDETECT,[44] which is based on data from the classical Blackwell experiments of the 1940s where subjects were tasked with the identification of circular targets against uniform backgrounds.[45] The last sub model takes the MRVD and estimates threshold legibility luminance and back-calculates the retroreflectivity needed at the standard measurement geometry of 0.2 and -4.0 degrees for the observation and entrance angles, respectively.

Because of the infinite number of possible scenarios in terms of the combination of sign types, sign locations, driver needs, headlamp performance variations, and the like, several scenarios were selected to represent typical or design conditions. For instance, the driver was assumed to be 47 years old, and the dimensions of the vehicle approximated a large passenger sedan. The assumed headlamp was a composite headlamp representing the median performance of 26 headlamps from passenger cars with model years ranging from 1985 to 1990.

The results of this initial work were summarized in four tables of minimum retroreflectivity levels, distinguished by the color of sign. There were separate tables for white signs, yellow and orange signs, green signs, and red signs. Depending on which of the four tables one was considering, the minimum retroreflectivity levels also depended on at least some of the following factors: roadway speed, sign size, type of retroreflective sheeting, sign location for green signs, and type of legend (symbol versus text). There was also a minimum contrast ratio of 4:1 required for white on red and white on green signs. Because this research was conducted in the early 1990s, the only types of microprismatic sheeting included in the recommendations were ASTM Types IV and VII.

B. 1998 MINIMUM LEVELS

After the 1993 proposed minimum retroreflectivity levels were published, the developers of CARTS received many comments questioning the modeling assumption of one headlamp with the driver directly above the headlamp (also called Cyclops modeling). In reality, this modeling represents a motorcycle rather than a four-wheeled vehicle. Because of retroreflective sheeting materials' sensitivity to observation angle, a Cyclops modeling assumption can produce significantly different results than a model with the proper positioning of the headlamps with respect to the driver's eye position. In July 1994, the developers of CARTS provided a refined version that accounted for the effect of two headlamps on the observation angle.[46]

Shortly thereafter, the FHWA sponsored two research projects to determine the adequacy of the 1993 minimum retroreflectivity levels.[47, 48] During the same period, the FHWA also sponsored three national workshops to solicit input regarding the 1993 minimum retroreflectivity levels. In 1998, a report by McGee and Paniati listed the following reasons for revising the minimum retroreflectivity levels:[41]

- The results from research that utilized a human factors and mathematical modeling approach to consider the range of visual, cognitive, and psychomotor capabilities of the driving population and the complexity of the relationships between the driver, the vehicle, the roadway environment, and the sign (in other words, the refined version of CARTS).
- The results of human factors research to evaluate the percent of drivers than would be accommodated by signs with varying levels of retroreflectivity (in other words, the Mercier et al. research).[46, 47]
- The results from measurements made on over 20,000 in-service signs in over 50 States and local jurisdictions (data from three different reports).[42, 49, 50]
- Input received from the more than 40 State and local jurisdictions represented at the three regional workshops held in Baltimore, MD, Kansas City, MO, and Denver, CO, in late 1995.
- Input from public agency and private industry representatives received at numerous presentations.

The revisions in 1998 resulted in several changes, but the most evident change was the removal of all minimum retroreflectivity levels for overhead signs because of many unresolved issues with vehicle headlamp performance specifications and the difficulty in measuring overhead sign retroreflectivity.[49] The minimum retroreflectivity levels for red, yellow, and orange signs were slightly reduced. Most of the minimum retroreflectivity levels for white signs were reduced, but a few were raised. The minimum retroreflectivity levels for ground mounted green signs, which did not include street name signs, stayed the same.

C. 2001 MINIMUM LEVELS FOR OVERHEAD AND STREET NAME SIGNS

In March 1997, the NHTSA implemented a final rule that revised FMVSS 108 in order to address the issue of headlamp misaim, which was believed to be a significant factor related to the amount of glare and the variability of headlamp luminous intensity directed toward overhead signs. The final rule reflects the consensus of the negotiated rulemaking concerning the improvement of headlamp aim ability performance and visual/optical headlamp aiming.

The final rule established improved headlamp aiming features that provide more reliable and accurate aiming and help vehicle operators more easily determine the need for correcting aim. The rule introduced visually/optically aimed headlamps to the United States. The term "VOA" generically describes two types of visually/optically aimed headlamps: VOR and VOL headlamps. The VOL headlamp is a low beam with a horizontal cutoff to the left side of the beam. The VOR headlamp is a low beam and has a horizontal cutoff to the right side of the beam. VOL headlamps can reduce glare to oncoming drivers compared to conventional U.S. low beams. VOR headlamps have less ability to reduce oncoming glare but produce luminous intensity distributions more similar to conventional U.S. low beams.

Because of the NHTSA's revision to *FMVSS 108*, the FHWA sponsored a research project to develop minimum retroreflectivity levels for overhead signs. In order to complete the initial set of minimum retroreflectivity recommendations, the FHWA also included minimum retroreflectivity levels for street name signs in the scope of the project. The research included the development of an analytical process to determine minimum retroreflectivity levels from a host of factors including demand luminance. To determine the adequate demand luminance values, the researchers performed a legibility study with full-scale guide signs and street name signs. Special emphasis was devoted to accommodating older drivers. The results of the study were published in 2003 and included research recommendations for a set of minimum retroreflectivity levels for overhead and street name signs.(51)

Besides providing recommendations for minimum retroreflectivity levels for overhead and street name signs, the researchers also performed sensitivity analyses to determine the relative impact of factors such as the assumed design driver capabilities, the headlamp type, and the vehicle type. This research identified a need to update some of the key assumptions of the initial 1993 and revised 1998 minimum retroreflectivity levels. In addition, there was a need to develop minimum retroreflectivity levels for the various types of retroreflective sheeting that had been introduced into the market since the earlier works' completion.

D. 2003 MINIMUM LEVELS

Because of a demonstrated need to update the minimum retroreflectivity levels for traffic signs, FHWA sponsored additional research focused on the investigation and sensitivity of updated factors such as the driver age, headlamps, vehicle types, and retroreflective sheeting. More specifically, this work included the use of an older design driver, newer style headlamps, larger vehicle types such as sport-utility vehicles (SUVs), and much more robust retroreflectivity prediction tools. The specifics of the update are reported in an FHWA report, and a summary paper is provided in the Transportation Research Record 1824.(52, 53)

The key updates included using an older driver in the analyses, a larger vehicle that is more representative of large SUVs, a more modern headlamp profile, and additional sign sheeting materials that were not included in the initial analyses.

RECOMMENDED MINIMUM RETROREFLECTIVITY LEVELS

The results of all this research led to the minimum maintained traffic sign retroreflectivity levels shown in table A1.

Table A1. Minimum Maintained Traffic Sign Retroreflectivity Levels.①

<table>
<tr><th rowspan="3">Sign Color</th><th colspan="4">Sheeting Type (ASTM D4956-04)</th><th rowspan="3">Additional Criteria</th></tr>
<tr><th colspan="3">Beaded Sheeting</th><th>Prismatic Sheeting</th></tr>
<tr><th>I</th><th>II</th><th>III</th><th>III, IV, VI, VII, VIII, IX, X</th></tr>
<tr><td rowspan="2">White on Green</td><td>W*; G ≥ 7</td><td>W*; G ≥ 15</td><td>W*; G ≥ 25</td><td>W ≥ 250; G ≥ 25</td><td>Overhead</td></tr>
<tr><td>W*; G ≥ 7</td><td colspan="3">W ≥ 120; G ≥ 15</td><td>Ground-mounted</td></tr>
<tr><td rowspan="2">Black on Yellow
or
Black on Orange</td><td>Y*; O*</td><td colspan="3">Y ≥ 50; O ≥ 50</td><td>②</td></tr>
<tr><td>Y*; O*</td><td colspan="3">Y ≥ 75; O ≥ 75</td><td>③</td></tr>
<tr><td>White on Red</td><td colspan="4">W ≥ 35; R ≥ 7</td><td>④</td></tr>
<tr><td>Black on White</td><td colspan="4">W ≥ 50</td><td>—</td></tr>
</table>

① The minimum maintained retroreflectivity levels shown in this table are in units of $cd/lx/m^2$ measured at an observation angle of 0.2 ° and an entrance angle of -4.0 °.
② For text and fine symbol signs measuring at least 1200 mm (48 inches) and for all sizes of bold symbol signs
③ For text and fine symbol signs measuring less than 1200 mm (48 inches)
④ Minimum Sign Contrast Ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)
* This sheeting type should not be used for this color for this application.

Bold Symbol Signs

- W1-1, -2 – Turn and Curve
- W1-3, -4 – Reverse Turn and Curve
- W1-5 – Winding Road
- W1-6, -7 – Large Arrow
- W1-8 – Chevron
- W1-10 – Intersection in Curve
- W1-11 – Hairpin Curve
- W1-15 – 270 Degree Loop
- W2-1 – Cross Road
- W2-2, -3 – Side Road
- W2-4, -5 – T and Y Intersection
- W2-6 – Circular Intersection
- W3-1 – Stop Ahead
- W3-2 – Yield Ahead
- W3-3 – Signal Ahead
- W4-1 – Merge
- W4-2 – Lane Ends
- W4-3 – Added Lane
- W4-5 – Entering Roadway Merge
- W4-6 – Entering Roadway Added Lane
- W6-1, -2 – Divided Highway Begins and Ends
- W6-3 – Two-Way Traffic
- W10-1, -2, -3, -4, -11, -12 – Highway-Railroad Advance Warning
- W11-2 – Pedestrian Crossing
- W11-3 – Deer Crossing
- W11-4 – Cattle Crossing
- W11-5 – Farm Equipment
- W11-6 – Snowmobile Crossing
- W11-7 – Equestrian Crossing
- W11-8 – Fire Station
- W11-10 – Truck Crossing
- W12-1 – Double Arrow
- W16-5p, -6p, -7p – Pointing Arrow Plaques
- W20-7a – Flagger
- W21-1a – Worker

Fine Symbol Signs – Symbol signs not listed as Bold Symbol Signs.

Special Cases

- W3-1 – Stop Ahead: Red retroreflectivity ≥ 7
- W3-2 – Yield Ahead: Red retroreflectivity ≥ 7; White retroreflectivity ≥ 35
- W3-3 – Signal Ahead: Red retroreflectivity ≥ 7; Green retroreflectivity ≥ 7
- W3-5 – Speed Reduction: White retroreflectivity ≥ 50
- For non-diamond shaped signs such W14-3 (No Passing Zone), W4-4p (Cross Traffic Does Not Stop), or W13-1, -2, -3, -5 (Speed Advisory Plaques), use largest sign dimension to determine proper minimum retroreflectivity level.

It was noted that there may be conditions where the minimum retroreflectivity levels shown in table A1 would not provide adequate nighttime visibility. It was also noted that if the worst case scenario was chosen for the analyses, there would be no type of retroreflective sheeting that could provide adequate luminance levels to achieve detection and legibility for all drivers.

The development of the updated minimum retroreflectivity levels consisted of many different scenarios comprised of a variety of practical and typical speeds, roadway cross sections, vehicle types, sign positions, sign sizes, headlamp types, etc. Ultimately, the minimum retroreflectivity levels were derived from the equilibrium point of demand and supply luminance levels, which also vary as a function of the aforementioned factors. (It is important to note that luminance and retroreflectivity are not synonymous terms. Briefly, luminance is the perceived brightness of a sign, and retroreflectivity is a property of the sign that describes its efficiency to return headlamp illuminance back toward the driver.) Technically, each specific scenario for each specific driver has a unique minimum luminance and therefore a unique minimum retroreflectivity level associated with that situation. However, from a practical point of view, the minimum retroreflectivity levels need to be easy to measure and manage. This requires that the infinite number of minimum retroreflectivity levels associated with the infinite number of driving scenarios be consolidated to a practical and manageable number.

The level of complexity of the framework of the minimum retroreflectivity levels of 1993 and 1998 was a particularly significant issue as seen by the AASHTO Special Retroreflectivity Task Force. As the research effort to update the minimum retroreflectivity levels was nearing completion, the researchers focused on consolidating the recommendations into an easy-to-use format. In consolidating the minimum retroreflectivity levels, certain decisions were made regarding the resolution of the levels. For example, factors such as sign size and roadway speed were collapsed into one level representing the majority of typical driving scenarios for a given sign type.

The consolidation efforts were progressing as a second round of national minimum retroreflectivity workshops was underway.(54) The most current research recommendations regarding the consolidation of the minimum retroreflectivity levels were presented to the participants of each of the four workshops. The input received from the workshop participants helped shape the outcome of the recommended minimum retroreflectivity levels presented in this paper.

The consolidation efforts ultimately resulted in some degree of compromise between the precision and the brevity of the minimum retroreflectivity levels. The final research report provides a detailed description of how the minimum retroreflectivity levels were consolidated to an implementable format.(52)

KEY ASSUMPTIONS

The minimum retroreflectivity levels shown in table A1 represent the most recent results of a series of research studies that have been undertaken over the past two decades. They also represent the latest efforts in a long series of considerations related to providing safe and efficient roadways. The key assumptions associated with table A1 are

- These minimum retroreflectivity levels represent driver needs in dark rural conditions with essentially no ambient lighting, no glare except from the vehicle instrument panel, and no visual complexity.
- The nighttime driver needs used to develop the minimum retroreflectivity levels can be expressed as accommodating sign legibility or recognition for 50 percent of drivers over 55 years of age.
- The required legibility distances were based on a legibility index of 12.2 meters (40 feet) per inch of letter height.
- The required recognition distances were based on CARTS MRVD values.
- In conditions where the required threshold luminance levels were below 1.0 cd/m^2, a minimum of 1.0 cd/m^2 was assumed for maintenance of sign conspicuity.
- The supply sign luminance was modeled assuming that the only contribution of illuminance originated from the design vehicle. In other words, no contribution from other vehicles in the proximity of the design vehicle was considered. There was also no consideration of pavement reflection adding to the luminance of the sign.(55)
- The supply luminance did consider windshield transmissivity (0.72/km) and atmospheric transmissivity (0.86/km).
- The headlamp luminous intensity matrix used for developing the minimum retroreflectivity levels representing a market-weighted model year 2000 passenger car. The data were derived from measurements made with perfect aim, no scattering of light caused by lens wear or dirt, and a voltage of 12.8 volts.
- The retroreflectivity data used for the analysis and modeling was the same as is included in the ERGO2001 program. While the retroreflective sheeting materials used throughout this paper are classified using the ASTM D-4956-04 classification scheme, it is important to note that the retroreflectivity data from the EGRO2001 model do not necessarily represent all manufacturers' sheeting performance within each ASTM Type designation. For instance, there are several manufacturers of high intensity retroreflective material (ASTM Type III). Each brand performs differently. This is particularly true for microprismatic sheeting materials.
- Minimum retroreflectivity levels developed for straight and flat roadways (i.e., no curves).
- Vehicle dimensions represented a contemporary-styled sport utility vehicle.
- Signs were installed normal to the roadway.

REFERENCES

1. "FHWA Fiscal Year 2003 Performance Plan." This document can be viewed at the Internet Web site: http://www.fhwa.dot.gov/reports/2003plan/index.htm.

2. "Traffic Safety Facts 2005: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System." Publication NO. DOT HS 809484 December 2006. This document can be viewed at the Internet Web site: http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2005.pdf

3. Federal Highway Administration and The Bureau of Transportation Statistics, 2001 National Household Travel Survey, (23.3% of vehicle miles traveled occur between 7:00 pm and 6:00 am). This document can be viewed at the Internet Web site: http://nhts.ornl.gov.

4. Staplin, L., Lococo, K., and Byington, S., *Older Driver Highway Design Handbook.* FHWA-RD-97-135, FHWA, Washington, D.C., 1998

5. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2003.

6. Carlson, P.J. and H.G. Hawkins, Jr. *Updated Minimum Retroreflectivity Levels for Traffic Signs.* FHWA-RD-03-81. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2004.

7. Carlson, P.J., G.H. Hawkins, Jr., G.F. Schertz, D.J. Mace, and K.S. Opiela. "Developing Updated Minimum In-Service Retroreflectivity Levels for Traffic Signs." In *Transportation Research Record 1824,* TRB, National Research Council, Washington, D.C., 2003, pp. 133–143.

8. Carlson, P.J. and H.G. Hawkins, Jr. *Minimum Retroreflectivity Values for Overhead Guide Signs and Street Name Signs.* FHWA-RD-03-82. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2003.

9. American Society for Testing and Materials. *Standard Specification for Retroreflective Sheeting for Traffic Control.* ASTM D4956-04, West Conshohocken, PA, 2004.

10. McGee, H.W. and S. Taori. *Impacts on State and Local Agencies for Maintaining Traffic Signs within Minimum Retroreflectivity Guidelines.* FHWA-RD-97-053, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1998.

11. *Traffic Control Device Handbook.* Institute of Transportation Engineers, Washington, D.C., 1999.

12. Hawkins, H.G., P.J. Carlson, G.F. Schertz, and K.S. Opiela. *Workshops on Nighttime Visibility of Traffic Signs: Summary of Workshop Findings.* FHWA-SA-03-002, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2003.

13. Hildebrand, E. “Reduction in Traffic Sign Retroreflectivity Caused by Dew and Frost.” Proceedings from TRB’s 82nd Annual Meeting, Washington, DC, January 2003.

14. Lagergren, E.A. *Traffic Sign Retroreflectivity Measurements Using Human Observers.* Report No. WA-RD-140.1, Washington State Transportation Center, Seattle, WA, 1987.

15. Hawkins, H.G. and P.J. Carlson.“Results of Visual Evaluations of Sign Retroreflectivity Compared with Minimum Retroreflectivity Recommendations.” In *Transportation Research Record 1754,* TRB, National Research Council, Washington, DC, 2001, pp. 11–20.

16. *How to Check Traffic Signs for Correct Reflectivity.* 3M Company, St. Paul, MN, 1957.

17. McGee, H.W. and D.L. Mace. *Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide.* FHWA-DF-88-001, FHWA, Washington, D.C., 1987.

18. Bischoff, A. and D. Bullock. *Sign Retroreflectivity Study.* FHWA-IN-JTRP-2002-22, FHWA, Washington, D.C., 2003.

19. Rasdorf, W.J., J.E. Hummer, E.A. Harris, V.P. Immaneni, and C. Yeom. *Designing an Efficient Nighttime Inspection Procedure to Ensure Motorist Safety.* FHWA/NC/2006-08, North Carolina State University, Raleigh, NC, 2006.

20. Black, K.L., H.W. McGee, S.F. Hussain, and J.J. Rennilson. *Service Life of Retroreflective Signs.* Report No. FHWA-RD-90-101, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1991.

21. Hawkins, H.G., P. J. Carlson, J.B. McCaleb, and C.R. McIlroy. *Impact of Minimum Retroreflectivity Values On Sign Replacement Practices.* FHWA/TX-97/1275-1F, College Station, TX, 1996.

22. W.D. Ketola. “Durability Testing for Retroreflective Sheetings.” In *Transportation Research Record 1230,* TRB, Washington, D.C., 1989.

23. Black, K.L., S.F. Hussain, and J.F. Paniati. “Deterioration of Retroreflection Traffic Signs.” *ITE Journal,* July 1992.

24. D.A. Andersen. *Sign Retroreflectivity Study.* North Dakota State University, North Dakota DOT, 1993.

25. W.D. Ketola. “Laboratory-Accelerated Versus Outdoor Weathering for Retroreflective Sheeting Specifications.” In *Transportation Research Record 1657,* TRB, Washington, D.C., 1999.

26. Montebello, D. and J. Schroeder. *Cost Effectiveness of Traffic Sign Materials.* MN/RC-2000-12, Minnesota DOT, St. Paul, MN, 2000.

27. Kirk, A.R., E.A. Hunt, E.W. Brooks. *Factors Affecting Sign Retroreflectivity.* SR514, Oregon DOT, Salem, OR, 2001.

28. Nuber, L. and D. Bullock. *Comparison of Observed Sign Retroreflectivity Values with Proposed FHWA Minimums.* TRB Annual Meeting, Washington, D.C., 2002.

29. Awadallah, F.*Durability of Retroreflective Signs.* Doctoral Dissertation–University of Maryland–Department of Civil Engineering, College Park, MD. 1987.

30. Kirk, A. R., E.A. Hunt, and E.W. Brooks. *Factors Affecting Sign Retroreflectivity.* Final report submitted to OR Department of Transportation, Salem, OR. 2001.

31. Wolshon, B., R. Degeyter, and J. Swargam. *Analysis and Predictive Modeling of Road Sign Retroreflectivity Performance.*16th Biennial Symposium on Visibility and Simulation, Iowa City, IA. 2002.

32. *Advance Notice of Proposed Amendments to the MUTCD: Minimum In-Service Retroreflective Performance of Traffic Control Devices.* Federal Register, Volume 50, Number 81, pp. 16,515–16,517, April 26, 1985.

33. United States Department of Transportation and Related Agencies Appropriations Act of 1992, Public Law 102–388, 106 Statute 1520, Section 406.

34. Mace, D.J., K. Perchonok, L.E. Pollack. *Traffic Signs in Complex Visual Environments.* FHWA-RD-82-102, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1982.

35. Mace, D.J., R.B. King, and G.W. Dauber. *Sign Luminance Requirements for Various Background Complexities.* FHWA-RD-85-056, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1985.

36. Mace, D.J., R.S. Hostetter, L.E. Pollack, and W.D. Zweig. *Minimal Luminance Requirements for Official Highway Signs.* FHWA-RD-86-151, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1986.

37. McGee, H.W. and D.J. Mace. *Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide.* FHWA-DF-88-001, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1988.

38. Mace, D.J., P.M. Garvey, and R.F. Heckard. *Relative Visibility of Increased Legend Size vs. Brighter Materials for Traffic Signs.* FHWA-RD-94-035, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1994.

39. Paniati, J.F. and D.J. Mace. *Minimum Retroreflectivity Requirements for Traffic Signs.* FHWA-RD-93-077, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., October 1993.

40. Paniati, J.F. and D.J. Mace. Minimum *Retroreflectivity Requirements for Traffic Signs, Summary Report.* FHWA-RD-93-152, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., October 1993.

41. McGee, H.W. and J.F. Paniati. *An Implementation Guide for Minimum Retroreflectivity Requirements for Traffic Signs.* FHWA-RD-97-052, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1998.

42. McGee, H.W. and S. Taori. *Impacts on State and Local Agencies for Maintaining Traffic Signs within Minimum Retroreflectivity Guidelines.* FHWA-RD-97-053, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1998.

43. Carlson, P.J. and H.G. Hawkins, Jr. "Minimum Retroreflectivity Values for Overhead and Street Name Signs." In *Transportation Research Record 1794,* TRB, National Research Council, Washington, D.C., 2002, pp.38–48.

44. Farber, E. and C. Matle. PCDETECT: A Revised Version of the DETECT Seeing Distance Model. *Transportation Research Record 1213.* Transportation Research Board, National Research Council, Washington, D.C., 1989.

45. Blackwell, H.R. "Contrast Thresholds of the Human Eye." *Journal of the Optical Society of America,* Volume 36, Number 11, November 1946.

46. Mercier, C.R., C. Goodspeed, C.J. Simmons, and J.F. Paniati. "Evaluation of Proposed Minimum Retroreflectivity Requirements for Traffic Signs." In *Transportation Research Record 1495,* TRB, National Research Council, Washington, D.C., 1995.

47. Goodspeed, C.H. and C.R. Mercier. *Nighttime Sign Visibility Performance.* Unpublished Draft Final Report, Federal Highway Administration, Washington, D.C., November 1993.

48. A.F. Bildstein, Jr. *The Effect of Environmental Illumination on Traffic Sign Conspicuity and Retroreflectivity.* Master of Science Thesis, College of Engineering and Mineral Resources, West Virginia University, Morgantown, WV, 2001.

49. Black, K.L., H.W. McGee, S.F. Hussain, and J.J. Rennilson. *Service Life of Retroreflective Signs.* Report No. FHWA-RD-90-101, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1991.

50. Black, K.L., H.W. McGee, and S.F. Hussain. *Implementation Strategies for Sign Retroreflectivity Standards.* NCHRP Report 346, Transportation Research Board, Washington, D.C., 1992.

51. Carlson, P.J. and H.G. Hawkins, Jr. *Minimum Retroreflectivity Values for Overhead Guide Signs and Street Name Signs.* FHWA-RD-03-82. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2003.

52. Carlson, P.J. and H.G. Hawkins, Jr. *Updated Minimum Retroreflectivity Levels for Traffic Signs.* FHWA-RD-03-81. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2004.

53. Carlson, P.J., G.H. Hawkins, Jr., G.F. Schertz, D.J. Mace, and K.S. Opiela. "Developing Updated Minimum In-Service Retroreflectivity Levels for Traffic Signs." In *Transportation Research Record 1824,* TRB, National Research Council, Washington, D.C., 2003, pp. 133–143.

54. Hawkins, H.G., P.J. Carlson, G.F. Schertz, and K.S. Opiela. *Workshops on Nighttime Visibility of Traffic Signs: Summary of Workshop Findings.* FHWA-SA-03-002, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2003.

55. P.J. Carlson. *A Model for Estimating Traffic Sign Illuminance and Luminance as a Function of Pavement Reflectance.* Doctorate of Philosophy, Texas A&M University, College Station, Texas, 2002.

Recycled
Recyclable

HRDS-05/11-07(WEB)E